

WHAT IS CLAIMED IS:

1. A semiconductor switching element driving circuit comprising:

a semiconductor switching element having a gate terminal, a first terminal and a second terminal for carrying a main current between the first and second terminals by applying a voltage to the gate terminal;

5 an overcurrent protection circuit for decreasing the main current at a first slope and then reducing the main current at a second slope steeper than said first slope, when said main current becomes a first overcurrent that exceeds a predetermined current value for a first  
10 period of time equal to or longer than a predetermined period of time; and

an overcurrent limiting circuit for  
instantaneously dropping the voltage applied to said gate  
terminal when said main current becomes a second  
15 overcurrent larger than said first overcurrent within a second period of time shorter than said predetermined period of time.

2. A semiconductor switching element  
20 driving circuit according to claim 1, wherein said overcurrent limiting circuit decreases the voltage applied to said gate terminal when said main current reaches said second overcurrent within a third period of time shorter than a delay time defined by said overcurrent

protection circuit.

3. A semiconductor switching element driving circuit comprising:

5 a semiconductor switching element having a gate terminal, a first terminal and a second terminal for carrying a main current between the first and second terminals by applying a voltage to the gate terminal;

10 an overcurrent limiting circuit for instantaneously dropping the voltage applied to said gate terminal when said main current becomes larger than a first comparison current; and

15 an overcurrent protection circuit for decreasing the main current at a first inclination when said main current becomes larger than a second comparison current that is lower than said first comparison current, and then reducing the main current at a second inclination steeper than said first inclination when the main current becomes smaller than a third comparison current that is lower than  
20 said second comparison current.

4. A semiconductor switching element driving circuit according to claim 3, wherein said semiconductor switching element further comprising:

25 a sense terminal connected to said semiconductor switching element for outputting a sense current substantially proportional to said main current; and

wherein said overcurrent protection circuit comprising:

a first comparison unit for judging whether said main current becomes larger than said second comparison current based on said sense current, and a second comparison unit for judging whether said main current becomes smaller than said third comparison current based on said sense current.

5 10 5. A semiconductor switching element driving circuit according to claim 4, wherein said overcurrent protection circuit comprising:

15 a delay circuit for delaying an output of said first comparison unit for a delay time, wherein said overcurrent protection circuit decreases said main current at said first inclination after said delay time has passed.

20 6. A semiconductor switching element driving circuit according to claim 5, wherein said overcurrent protection circuit comprising an overcurrent protection transistor having a collector connected to said gate terminal;

25 wherein said overcurrent protection circuit turns on said overcurrent protection transistor to reduce the voltage applied to said gate terminal when said second comparison unit detects said main current becomes smaller

than said third comparison current after said first comparison unit detects that said main current has become larger than said second comparison current.

5           7.       A semiconductor switching element driving circuit according to claim 6, wherein said overcurrent protection circuit comprising:

          a latch circuit for holding an output of said delay circuit; and

10           an AND circuit to which outputs of said latch circuit and said second comparison unit are inputted, wherein an on state and an off state of said overcurrent protection transistor depend on an output signal of said AND circuit.

15           8.       A semiconductor switching element driving circuit according to claim 1, further comprising:

          a sense terminal connected to said semiconductor switching element for carrying a sense current substantially proportional to said main current;

20           wherein said overcurrent limiting circuit comprising:

          an overcurrent limiting transistor having a collector connected to said gate terminal and a base to which a voltage controlled based on said sense current is applied, wherein said overcurrent limiting transistor is turned on to reduce the voltage applied to said gate

terminal based on said sense current.

9. A semiconductor switching element driving circuit according to claim 1 wherein said semiconductor switching element is an IGBT having a collector terminal as said first terminal and an emitter terminal as said second terminal.

10. A semiconductor switching element driving circuit according to claim 9, wherein said IGBT has a plurality of elements each having different threshold voltages and connected each other substantially in parallel.

11. A semiconductor switching element driving circuit according to claim 9, wherein said IGBT has a plurality of elements respectively forming channels in different plane directions, whereby threshold voltages of the elements are different from each other.

12. A semiconductor switching element driving circuit according to claim 11, wherein one of said plane directions is {100}.

13. A semiconductor switching element driving circuit according to claim 12, wherein said IGBT comprising:

a gate electrode being connected to said gate terminal of said IGBT, forming a top geometry thereof in a hexagonal shape on a plane parallel to a surface of a semiconductor substrate on which the IGBT is formed, and having a plurality of faces each orienting different plane directions, wherein one of said plane directions is {100}.

14. A semiconductor switching element driving circuit according to claim 9, wherein said IGBT has a gate electrode having a striped shape, and forming channels on both sides of said gate electrode, and having different threshold voltages on both sides of the gate electrode.

15. A semiconductor switching element driving circuit according to claim 14, wherein the threshold voltage on one of said both sides of said gate electrode is varied by conducting an obliquely ion implantation with respect to a surface of a semiconductor substrate on which the IGBT is formed for adjusting the threshold voltage.

16. A semiconductor switching element driving circuit according to claim 1, wherein said semiconductor switching element driving circuit is utilized to an automobile motor driving circuit for controlling a motor of an electric vehicle or hybrid

vehicle.

17. A semiconductor switching element driving circuit according to claim 1, further comprising:

a sense terminal connected to said semiconductor switching element for carrying a sense current substantially proportional to said main current;

wherein said overcurrent limiting circuit comprising:

a current detection resistance connected to said sense terminal for converting said sense current outputted from the sense terminal into a detection voltage; and

a detection resistance switching unit for decreasing a resistance value of said current detection resistance until said voltage applied to the gate terminal is under a predetermined value which is lower than a full-on voltage by which said semiconductor switching element becomes a full on state.

5 18. A semiconductor switching element driving circuit comprising:

a semiconductor switching element having a gate terminal, a first terminal and a second terminal for carrying a main current between the first and second  
10 terminals by applying a control voltage to the gate terminal, said semiconductor switching element outputting a detection current substantially

proportional to the main current from a detection terminal; and

an overcurrent limiting circuit for adjusting the control voltage applied to said gate terminal so that  
5 said main current becomes equal to or under a predetermined current value, wherein said overcurrent limiting circuit comprising:

a current detection resistance connected to a detection terminal for converting said detection current  
10 outputted from the detection terminal into a detection voltage; and

a detection resistance switching unit for decreasing a resistance value of said current detection resistance until said gate voltage applied to the gate  
15 terminal is under a reference voltage which is lower than a full-on voltage by which said semiconductor switching element becomes a full on state.

19. A semiconductor switching element  
20 driving circuit according to claim 18, wherein said detection resistance switching unit comprising:

a control voltage detecting unit for detecting said control voltage;

a short-circuiting unit for short-circuiting a  
25 part of said current detection resistance; and

a short circuit driving unit for decreasing the resistance value of said current detection resistance by



driving said short-circuiting unit during said control voltage detected by said control voltage detecting unit is under the reference voltage.

5                   20.     A   semiconductor   switching   element driving circuit according to claim 19, wherein said current detection resistance comprising a first detection resistance connected to a second detection resistance in series;

10                   wherein     said     short-circuiting     unit short-circuits one of said first detection resistance and said second detection resistance.

21.     A   semiconductor   switching   element driving circuit according to claim 18, wherein said semiconductor switching element is an IGBT having a gate terminal as said control terminal, a collector terminal as said first terminal, and an emitter terminal having a main emitter terminal as said second terminal and a sub emitter terminal as said detection terminal.